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Designing Radial Sliding Bearing Equipped with Hydrostatically Suspended Pads

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Abstract

Operating experience indicates that the installation of the damping bearings with the hydrostatic self-generative oil film can increase the unity reliability and efficiency, reduce vibration levels, including under transient and non-stationary modes of operation, ensures a smooth transition through critical frequencies.

Keywords: Radial sliding bearing; turbocompressors; hydrostatically suspended pads.

The assembly units specifying reliability of operation of modern high-speed turbocompressors, turbo refrigerating machines, multipliers, and pump units are the assembly units of sliding bearings

The sliding bearings of a traditional design, which are now regular at a majority of units, have a number of deficiencies among which, first of all, it is possible to specify the followings:

- Insufficient bearing capacity and damping ability that results in their intensive wearing, increased losses of power and lubricant consumption under transitional conditions and modes other than nominal ones;
- Support surfaces of the bearing pads are subject to increased mechanical wearing (so-called bearing drawdown);
- The bearings require increased clearances in labyrinth seals because of high precession of rotor on start-up and shut down conditions;

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- The bearings are capable to produce auto-oscillations by the forces of oil excitation arising in a hydrodynamic bearing layer;
- They are not protected from spark-wear.

In particular, in work [1], there is described the use of various operating conditions for bearings of various designs: multilobe journal, segmented, combined bearings, but any of these designs does not provide reliable operation on start-up and transient conditions and effective damping in the whole spectrum of vibration frequencies.

As a consequence of the aforesaid conclusion, the standard bearings do not comply with the requirement of 2 … 4 year proper continuous maintenance in the dynamic equipment**.** The most effective way to expand the range of stable operation of the rotor – bearing system is an application of the supports, which are capable not only to withstand the appearance of auto-oscillations, but also actively to suppress occurring vibration.

In 1970, the Pioneer Motor Bearing Co Company developed and successfully implemented a radial bearing with self-aligning pads on hydrostatic suspension [2], which was devoid of the major drawbacks of the traditional sliding bearings. Owing to the high operation performances, the design of the journal bearings with the self-aligning hydrostatically suspended pads was widely and successfully applied by the TRIZ LTD Company at solution of various problems of the dynamic equipment [3] operation

Special feature of these bearings (fig. 1) is the presence of the self-generated hydrostatic suspension for the self–aligning bearings, which is formed at the expense of taking off a portion of the hydrodynamic lubricant from the bearing hydrodynamic layer through the hole in the pad into the hydrostatic pocket located on the back side of the pad. Thus, in the pocket, there is created hydrostatic pressure due to which the pad floats, and the lubricant is throttled over the pad back.

The absence of the bearing mechanical contacts not only provides simplifying the design but also prevents abrasion of the bearing surfaces of the pad back and the housing of the bearing but eliminates the problems associated with so-called bearing drawdown, ensures a long service life of the assembly unit without changing pads. The additional degree of the pad mobility in the bearing on hydrostatic suspension ensures its mobility in the transverse direction and in the angular direction as well.

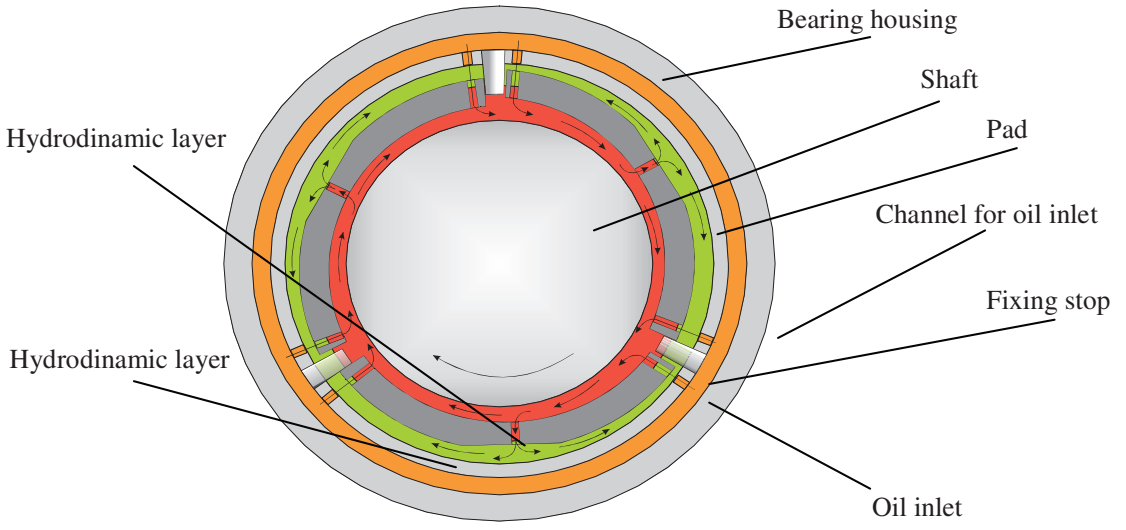

Fig. 1. Radial bearing with pads on hydrostatic suspension

The presence of hydrostatic suspension allows the pads to monitor oscillations of the shaft and to damp them at the expense of viscous forces of the hydrostatic layer that is not present in bearings of traditional designs. Due to the above said feature, the bearings of this type have a high damping ability, which allows (the fact has been repeatedly confirmed in practice), at the expense of the effective damping of the shaft oscillations, several times to reduce vibration levels, regardless of the source, and it is their essential advantage over the other types of sliding bearings.

For the first time, the three-segmented damping bearings on the hydrostatic film developed by the specialists of TRIZ LTD Company were applied as a part of a centrifugal high-pressure compressor for the cycling process unit at the Timofeevskaya Gas Condensate Field. While performing start-up and adjustment procedures at commissioning the compressor (UKSP-500) of 16 MW capacity the specialists faced the vibration problem for the high pressure compressor rotor because of aerodynamic excitation in the flowing part. The hydrodynamic bearing with five self-aligning pads damped insufficiently at energizing the prototype natural gas compressor. When entering the operating condition (11 300 rpm), the rotor vibro–shifting reached up 400 microns.

After installing the three-segmented damping bearing, the rotor vibration decreased by ten times. The special structural measures were taken to decrease the temperature of the bearing hydrodynamic film (fig. 2): the distributive groove at the front edge was performed with a slitted channel directed from the groove to the end face of the pad against the direction of the shaft rotation, and at the trailing edge, there was performed a special slot for draining hot lubricant. To provide for the hot lubricant effective removal from the shaft, in the slot there was set a scraper made of wear-resistant and antiscuff material. And the scraper design was provided of such a form that allowed displacing the scraper around its longitudinal axis to compensate for its wear while removing hot lubricant.

The calculations showed that the use of the oil scrapers reduced the maximum temperature of the lubricating layer by about of 10°C to 20°C, thereby the bearing capacity could be of 1.5 .to. 2 times increased in the housings where it had been limited by the maximum temperature of the lubricating layer [4]. To reduce the temperature of the hydrodynamic film at the most loaded portion of the pad, in the body of this pad portion at its trailing edge, there were executed a number of holes with axes parallel to the longitudinal axis of the bearing, as well as organized the oil flow through the openings for additional cooling the most thermoloaded zone of the pad [5].

As a result, all the above said measures in a complex made it possible to reduce the temperature of the bearing up to the allowed values and to achieve the operating rotational speed, keeping the rotor vibration within normal limits.

Thus, the operation and refinement of the damping journal bearings on the hydrostatic film had provided for the necessary information to develop the design of bearings, as well as to improve their performances. In 1991, for the first time, the bearing housing was performed split, and the oil scraper installed between the pads [6], [7], [8].

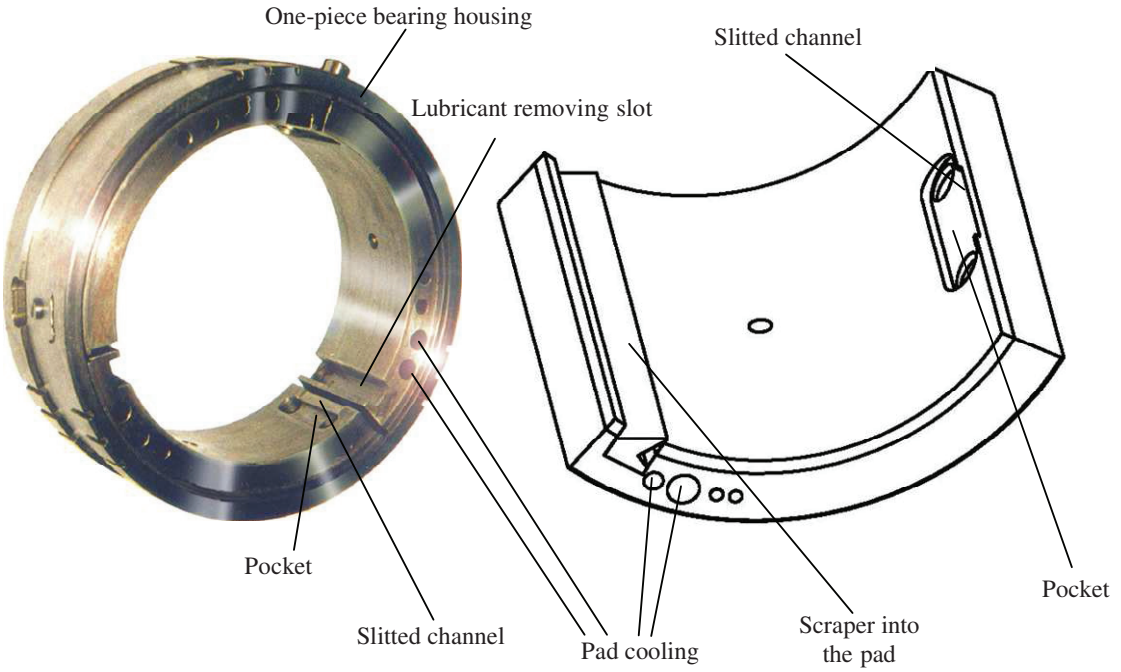

Fig. 2. Three-segmented damping bearing on hydrostatic film for cycling process compressor

The above said improvements made it easier to assemble the bearing and increased its maintainability (Fig. 3).

Along with the improvement of design, the specialists of the TRIZ LTD Company had been developing the bearing designs to improve the wear resistance of the bearing itself and the shaft neck as well. In 1991, there was developed a method of hardening the shaft necks by electro-erosion alloying (EEA), followed with plastic deformation (EEA with PPD). The technology has been tested and approved at the enterprises of JSC MCC EuroChem, Novomoskovsk, JSC DneprAZOT, Dneprodzerzhinsk, Mironovskaya and Uglerodskaya State District Power Stations (SDPSs), ORIANA Concern, Kalush.

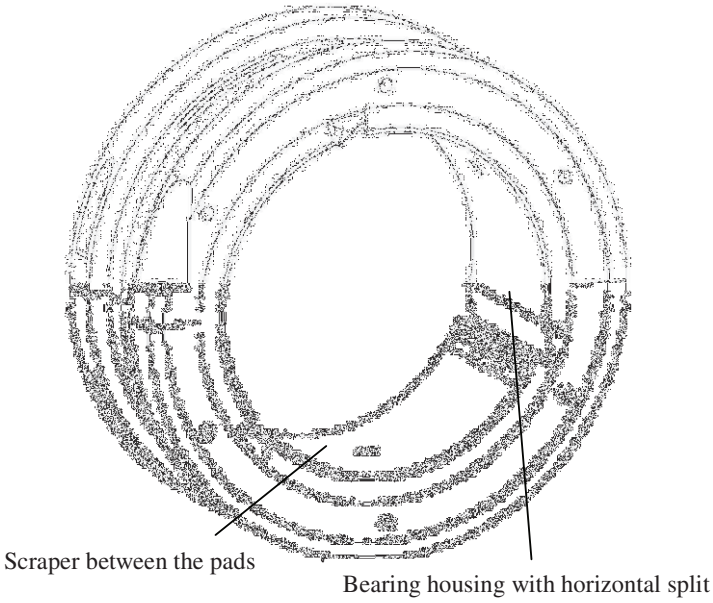

Fig. 3. Upgraded damping journal bearing on hydrostatic film

Owing to their reliability and high damping properties, the journal bearings with the pads on the hydrostatic suspension, which were designed and manufactured by TRIZ LTD Company, have been successfully operating and effectively helping to solve the problems of dynamic stability of the rotors for centrifugal compressors and pump units, turbines, electric motors, generators of large power plants at various enterprises of chemical, oil and gas industry of the CIS countries. Table 1 shows some examples of changes in vibration state on applying the damping journal bearings on the hydrostatic film for compressor and pump units.

Typically, the vibrations of the rotors on the damping bearings under operation conditions were of 1.5 to 2 times decreased in comparison with the vibrations of the rotors on the standard sliding bearings at normal levels of vibration before the change, and of 2 to 3 times under conditions with elevated levels of vibration.

Table 1.

Unit Description	*Rotor Vibration*	
	Before Damping Bearing Setting	*After Damping Bearing Setting*
Compressor K-1290-121-1 (JSC DneprAZOT)	*5 mm/s*	*1.69 mm/s*
Compressor 11TK-1 (NAK AZOT)	*70...85 mkm*	*20...35 mkm*
Compressor GB-101, HPC (JSC Concern Styrol)	*50...60 mkm*	*15...20 mkm*
Pump NMP 3512 (NAK AZOT)	*25...30 mkm*	*8...15 mkm*
Synthesis-Gas TK Turbine 103JT (Odesskij Priportovy Zavod)	*50...60 mkm*	*20...30 mkm*

At the same time, the journal bearings on the hydrostatic film demonstrated high damping properties over the entire range of the frequency spectrum of vibrations, as well as fitness for work near the surge area and at critical rotational speeds.

Revealing is comparison of the operating performances of the standard journal bearings for pos. 103-JT turbine used in the workshop of ammonia production at Odesskij Priportovy Zavod (OPZ) and the bearings of the TRIZ LTD Company production (see Table 2.): As for bearing capacity, specific load and specific consumption, the bearings of the TRIZ LTD Company about 1.5 times exceed standard ones, and the vibration level of the turbine rotor was 5 times decreased after installation of the damping bearings.

Along with increased reliability and reduced vibration, applying damping journal bearings on hydrostatic film contributed to increasing efficiency of the units. This is caused by the fact that the values of the clearances in the labyrinth seals and their wearing indices while being in service are directly dependent on the precession level of the journal bearings in the rotor.

As practice shows, increasing the clearances in the standard seals due to excessive vibration of the rotor under the start and off-design operating conditions results in gradual reducing the compressor capacity.

Table 2.

Bearing modification	Bearing capacity, F, kgf	Sliding speed, V, m/s	Specific pressure, P, kgf/cm^2	Lubricant specific flow rate Q, l/min x t	Rotor vibration, δ, mkm
Standard bearing of PD-120 type	2300	70	28	15	35
PD-120 type Bearing of TRIZ LTD Company production	3600	70	42	11	7

In addition, as a result of mechanical wear during operation, the sliding journal bearings of traditional design are characterized by increasing the gap, so-called bearing drawdown (see photos in Fig. 7.). Respectively, there is increased the gap in the labyrinth seals. The use of the damping bearings can of 1.5 to 2 times reduce the precession of the shaft [9], and because of the absence of the mechanical contact and drawdown, provides high stability of gaps in service. Due to such a situation, in the labyrinth seals, there would be originally set the smaller gaps as compared to the standard bearings. Reducing power losses, which are associated with gas cross-flows in the labyrinth seals, can improve the efficiency of the unit and reduce power consumption by 0.8 to 1.5%, being for example equivalent to saving of 128 to 240 kW power for the GPA-C-16 gas-pumping unit.

The most effective reduction of leakage through the labyrinth seal is achieved at combined application of the damping journal bearings and labyrinth seals made of PEEK polymer material. This fact allows further 12% reducing flow rate of leakages in comparison with the standard bearings, and it provides the total 80% leakage reduction as compared to the standard bearings and seals made of aluminum.

At the same time the graphs in Fig. 8 shows that the replacement of the standard bearings by the magnetic bearings reduces the efficiency of the unit. Due to the fact that the gaps in the magnetic bearings are greater than in the traditional sliding bearings (radial clearance is approximately 0.5 mm), in the labyrinth seals, the clearances must be correspondingly greater. As a result, there significantly increases the leakage flow rate through the seals, and this reduces the efficiency of the unit for about 1-2%. For example, as for the GPA C-16 gas-pumping unit, it is equivalent to the loss of 160 to 320 kW of power.

In addition, the magnetic bearings are unstable in operation and do not provide for required security under transient conditions and in emergency situations that, at best, results in the replacement of the safety ball bearings, and, at worst, in the replacement or overhaul of the inner casing together with the rotor.

In 1999, when designing the bearing for the TG-30 turbine generator of 25 MW power with the rotor of 17000 kg weight, there was appeared a technical problem consisting in the necessity of the significant increase of the bearing capacity without changing the size of the same. In doing so, there were performed design solutions providing filling the diagrams of the hydrodynamic bearing layer, in particular the babbit surface at the pads edges had been made with the elliptical belts to prevent oil leakage from the hydrodynamic wedge in the axial direction. The most loaded pad was performed with a wider angle of coverage than the other two pads, and at its outlet, in the place of the traditional scraper, there was installed an insertion made of an anti-scuff material (Fig. 4). Such an insertion combined the functions of a scraper and a seal preventing leakages in the circumferential direction that also made it possible to fill the pressure diagram for the hydrodynamic layer [10], [11]. According to the calculations, those designs increased the bearing capacity by about 25% [4].

To prevent electro-erosion wearing in the damping journal bearings, there were used the oil scrapers made of electrically conductive material [6], [7], [8].

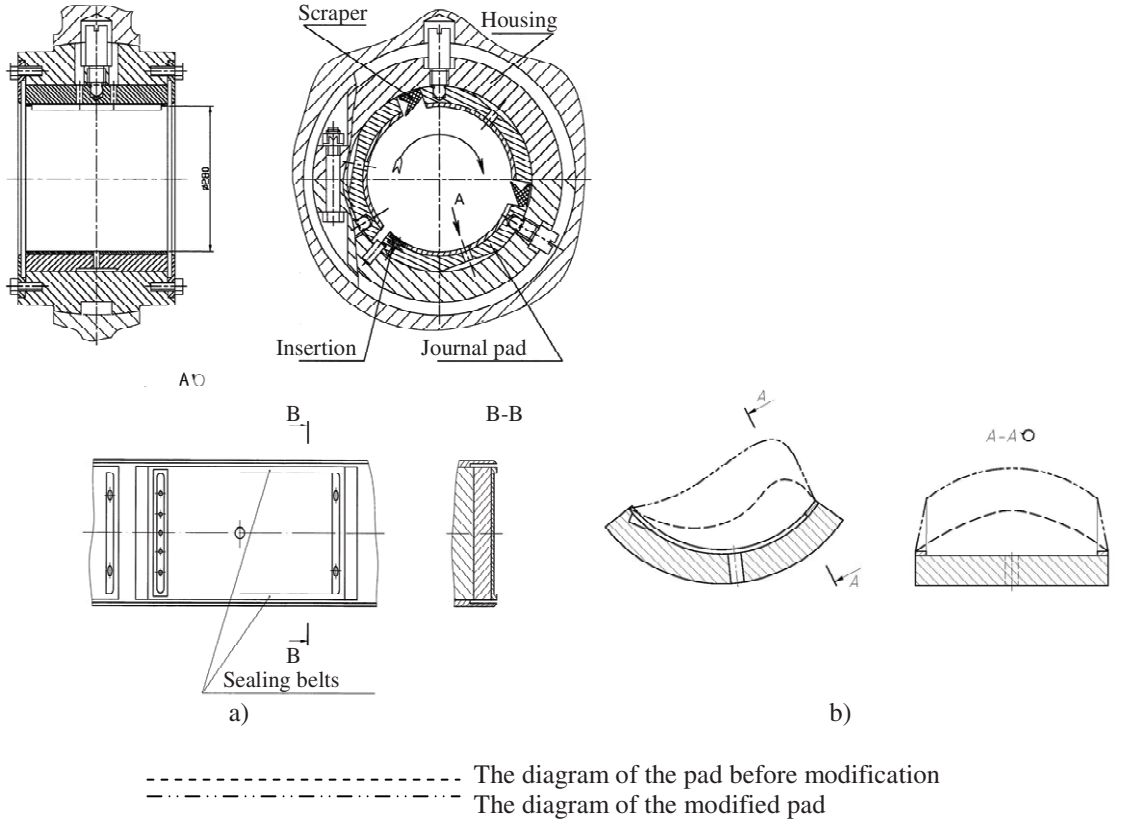

Fig. 4. Damping journal bearing of increased bearing capacity: a) The bearing scheme; b) The change of hydrodynamic pressure diagram of the layer

The use of the method of electro-erosion alloying (doping) (EEA) in the process of manufacturing and repairing the assembly units of the sliding bearings promoted enhancing their reliability and operating performances [13]. In 2003, there was designed and implemented the electro-spark technology for improving the quality of babbit layer adhesion due to availability of the transition layers. The essence of this technology consists in the fact that, on using the electro-spark method, the steel substrate is covered with a layer of copper, which in turn is poured by babbit (Fig. 5). This technology allows increasing the strength of steel substrate joint with the anti-friction babbit layer by 35% due to a stronger adhesive link between the babbitt and copper and the formation of diffusive link between copper and the steel substrate [14], [15].

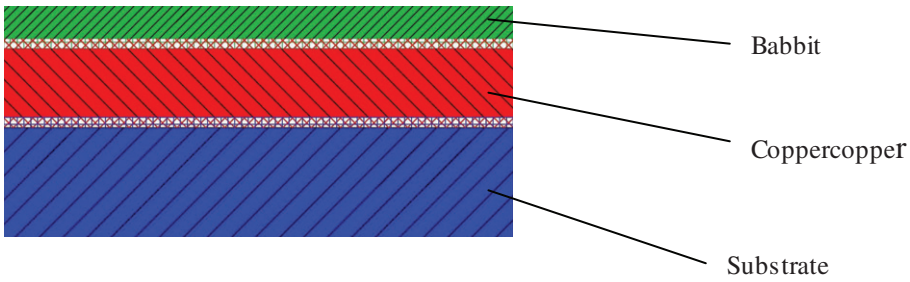

Fig. 5. Improving quality of babbit layer adhesion

The use of bronze pads instead of steel ones allows, due to bronze higher thermal conductivity, to improve heat removal from the bearing hydrodynamic wedge, reducing its temperature and increasing bearing capacity of the bearing assembly unit. In 2004, the specialists of TRIZ LTD Company, as a running-in coating for the bronze pads, developed the combined electro-erosion coating composition of such contents as: silver + copper + babbitt, silver + lead + silver, and silver + copper + silver + babbitt [16], [17]. The bronze pads with the above said coatings (Fig. 6) were well proven in operation. In 2004, there was also designed an anti-friction coating with regular micro relief, which improved the bearing capacity of the bearing assembly unit due to the changes in the diagram of the hydrodynamic layer.

Fig. 6. Bronze bearing pads with combined anti-friction coating

In 2005, there was designed a bearing having hydrostatic bearing pocket located on the inner surface of the bearing housing (Fig. 7).

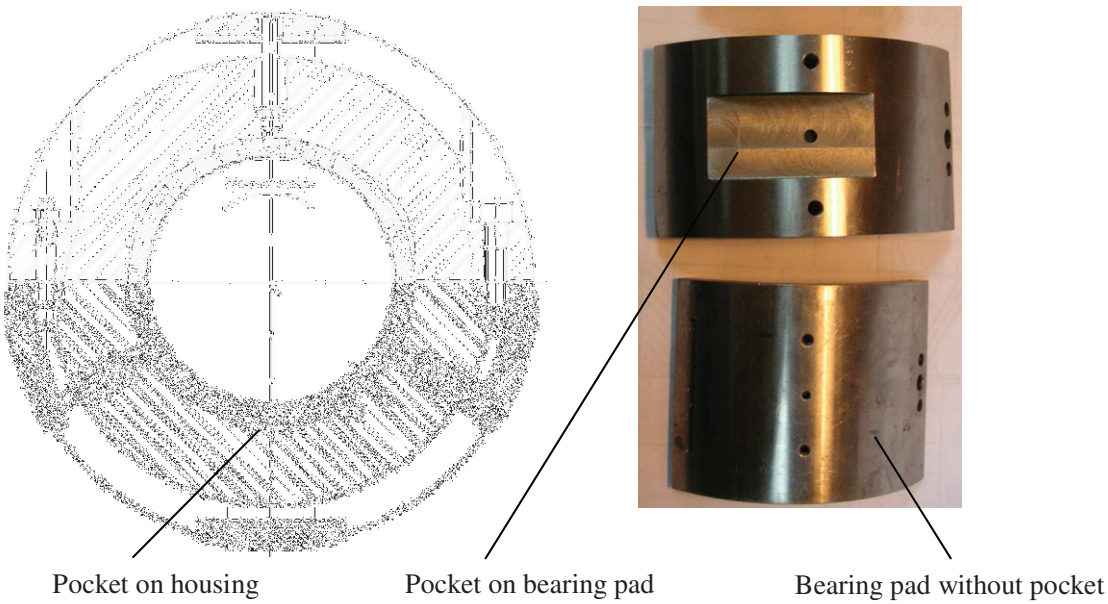

Fig. 7. Damping journal bearing with pocket on bearing housing

The replacement of the pocket from the bearing pad onto the inner surface of the housing of the bearing assembly unit makes it possible to reduce the thickness and mass of a self-setting pad minimizing its inertia, as well as improving the dynamic performances and increasing the stability of rotor-bearing system [6], [7], [8].

In 2006, there was designed a reversible damping journal bearing having the properties of non-reversible pads on the hydrostatic film, which bearing capacity and damping properties were the same as that of traditional non-reversible pads having been designed by TRIZ LTD Company [12]. Such a result was achieved due to the fact that on the back side of the pad, there was made not one but two symmetrically arranged hydrostatic pockets. Because of unequal hydrostatic pressure in the pockets, the position of the equally effective diagram on the back of the pad occurred offset to its middle in the direction of rotation, which was equivalent to the displacement of the hydrostatic pockets. Thus, there were provided the required properties of non-reversible pads, namely, high bearing capacity and robust vertical trajectory of a thorn

Reversibility of the bearing was ensured by the symmetrical arrangement of the pockets relative to the middle of the pad, because on changing the direction of the shaft rotation, there interchanged the pressure values in the hydrostatic pockets and accordingly redistributed the diagram of the hydrostatic pressure to adapt to the new direction of the rotor rotation (Fig. 8).

To provide for the reversive operation of the bearings, there were designed the reversible oil scrapers, which structures allowed them to perform their functions irrespective of the rotor rotation direction.

In 2007, there was developed a new method of hardening shaft bearing necks by electro-erosion alloying (EEA) with non-abrasive ultrasonic finishing the surface (EEL + NAUF). The method allowed achieving the following characteristics of the surface processed:

- Reducing the roughness (Ra) of 1.25 to 0.05 mkm;
- Increasing compressive stresses of 70 to 150 MPa;
- Forming a surface layer with a regular profile of microhardness 800 HV.

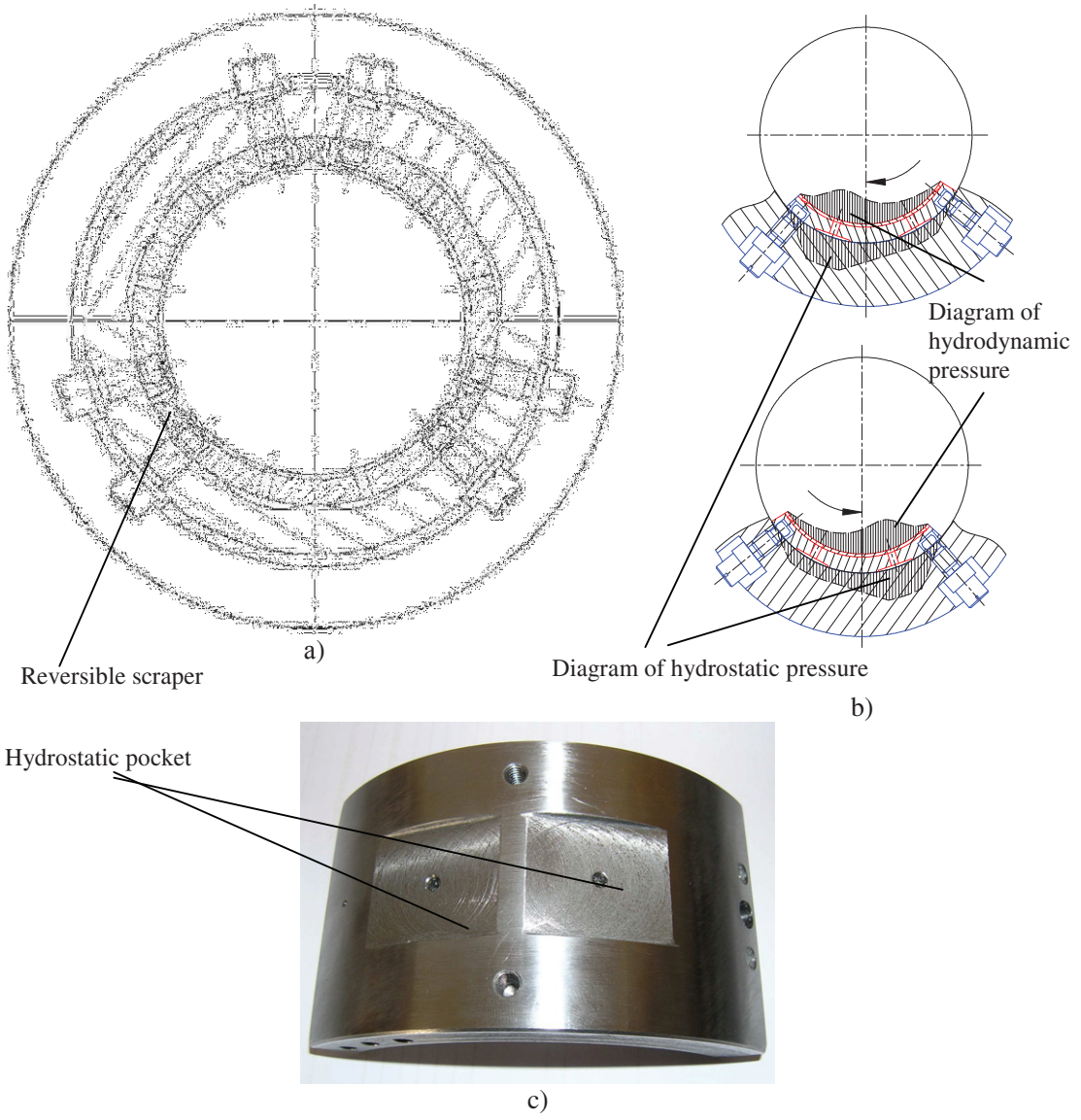

Fig.8. Reversible bearing with properties of non-reversible pads: a) – bearing scheme; b) – diagrams of hydrodynamic and hydrostatic pressures at different directions of the shaft rotation; c) – pad with two hydrostatic pockets

The bearings on the hydrostatic suspension of the TRIZ LTD Company production were patented in Ukraine, Russian Federation and Belarus. The range of the bearings currently delivered is characterized by the following parameters:

- shaft neck diameter - of 45 to 280 mm,
- rotational speed - of 1,500 to 30,000 rpm
- bearing loading - of 60 kgf to 17,000 kgf

Operating experience indicates that the installation of the damping bearings with the hydrostatic self-generative oil film can increase the unity reliability and efficiency, reduce vibration levels, including under transient and non-stationary modes of operation, ensures a smooth transition through critical frequencies. Even in the units, which are the most safety in terms of the dynamics, the damping bearings of 1.5 to 2 times reduce the precession of the shaft providing for stability of the gaps in the bearings, interstage and end seals, improve the reliability of the entire rotor system, prevent lowering productivity and efficiency of the unit by the end of the overhaul period, increase the service life, and reduce the costs for repairing the unit as a whole.

Currently, the TRIZ LTD Company continues developing the bearing designs improving them in the following areas:

- Researching and developing the damping sliding bearings equipped with thin-walled pads;
- Applying the thick anti-friction coating obtained with the use of electro-erosion alloying;
- Developing the technology of electro-erosion cementation and nitriding.

Thus, the radial damping bearings with the pads on the hydrostatic film, wherein there are used design and technological solutions of the TRIZ LTD Company, provide for eliminating the disadvantages of the sliding bearings of conventional designs.

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